(12) UK Patent Application (19) GB (11) 2 342 986 (13) A

(43) Date of A Publication 26.04.2000

(21) Application No 9920411.7

(22) Date of Filing 27.08.1999

(30) Priority Data
(31) 19839987 (32) 02.09.1998 (33) DE

(71) Applicant(s)
Siemens Aktiengesellschaft
(Incorporated in the Federal Republic of Germany)
Wittelsbacherplatz 2, D-80333 München,
Federal Republic of Germany

(72) Inventor(s)
Winfried Arz
Stefan Stocker

(74) Agent and/or Address for Service
Haseltine Lake & Co
Imperial House, 15-19 Kingsway, LONDON,
WC2B 6UD, United Kingdom

(51) INT CL[7]
G01R 27/16 // G01R 33/38 33/385

(52) UK CL (Edition R)
F4U UA U24A2 U29
H1T T3

(56) Documents Cited
US 5438182 A US 4593261 A US 4577175 A
Online (JAPIO) abstract for JP550070015

(58) Field of Search
UK CL (Edition R) F4U UA U23 U29, H1P PHC PSK, H1T T1F
INT CL[0] G01R 33/38 33/385, H01F 5/00 27/08 27/10 27/12 27/16
Online: EPODOC, JAPIO, WPI

(54) Abstract Title
Direct-cooled magnet coil

(57) Direct cooled magnet coil, in particular a gradient coil for magnetic resonance devices comprises a plurality of segmented conductors 2, 2 enclosing a cooling pipe 3. The cooling pipe 3 is made of a material that is not or is only slightly conductive electrically, in particular a flexible plastics material. The segments 2, 2 may be in the form of rectangular rods with channels 4 which are semicircular in cross section and which enclose the cooling pipe 3 in a locking manner. The cooling pipe 3 may have longitudinal webs and hooks for supporting the segments 2, 2.

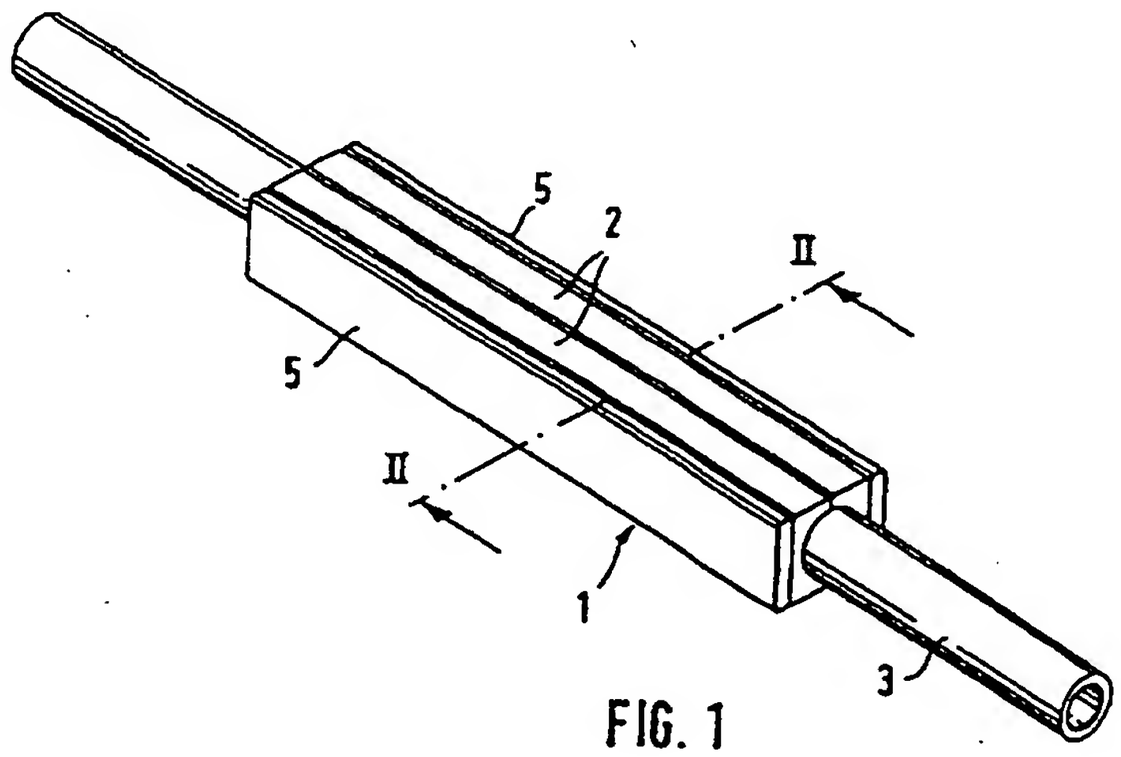

FIG. 1

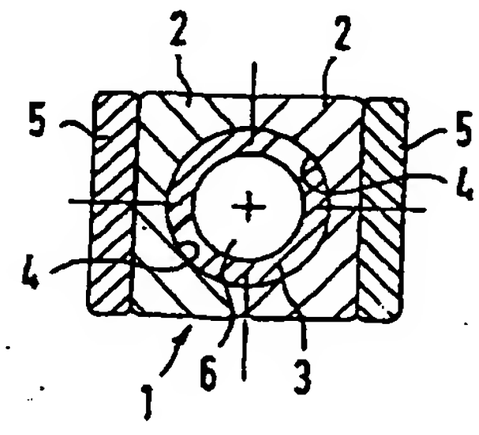

FIG. 2

GB 2 342 986 A

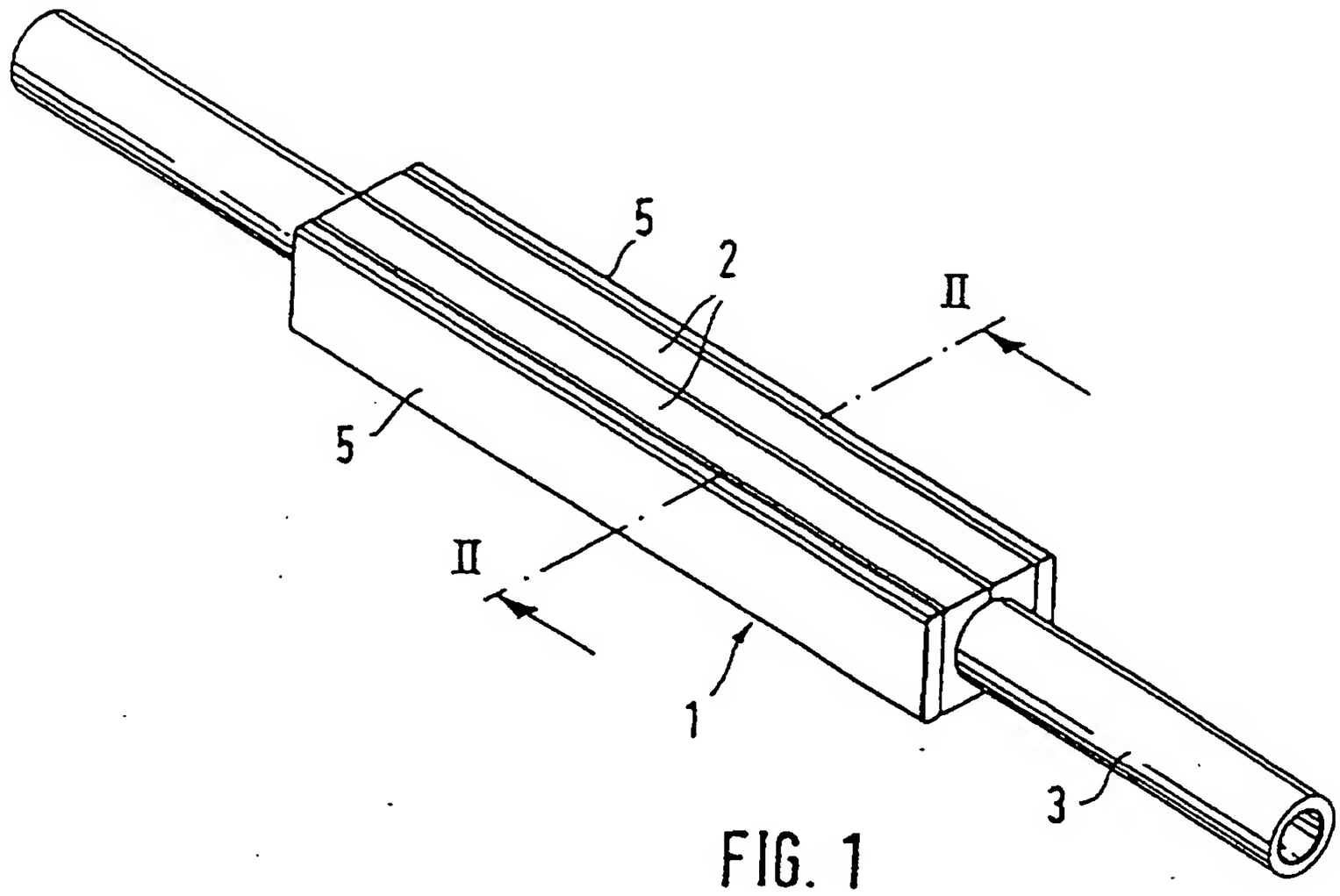

FIG. 1

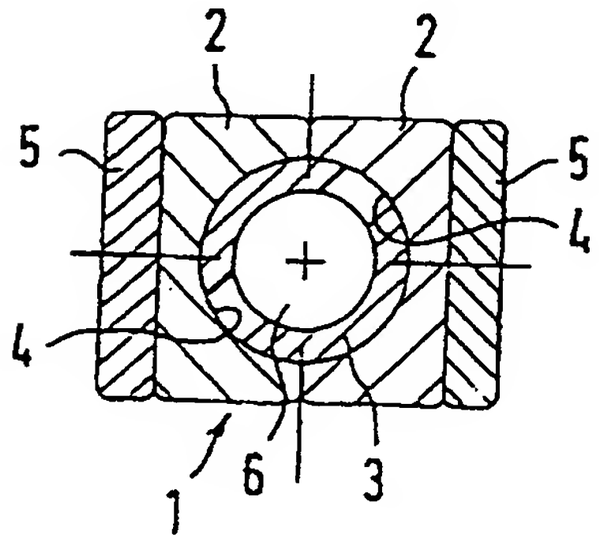

FIG. 2

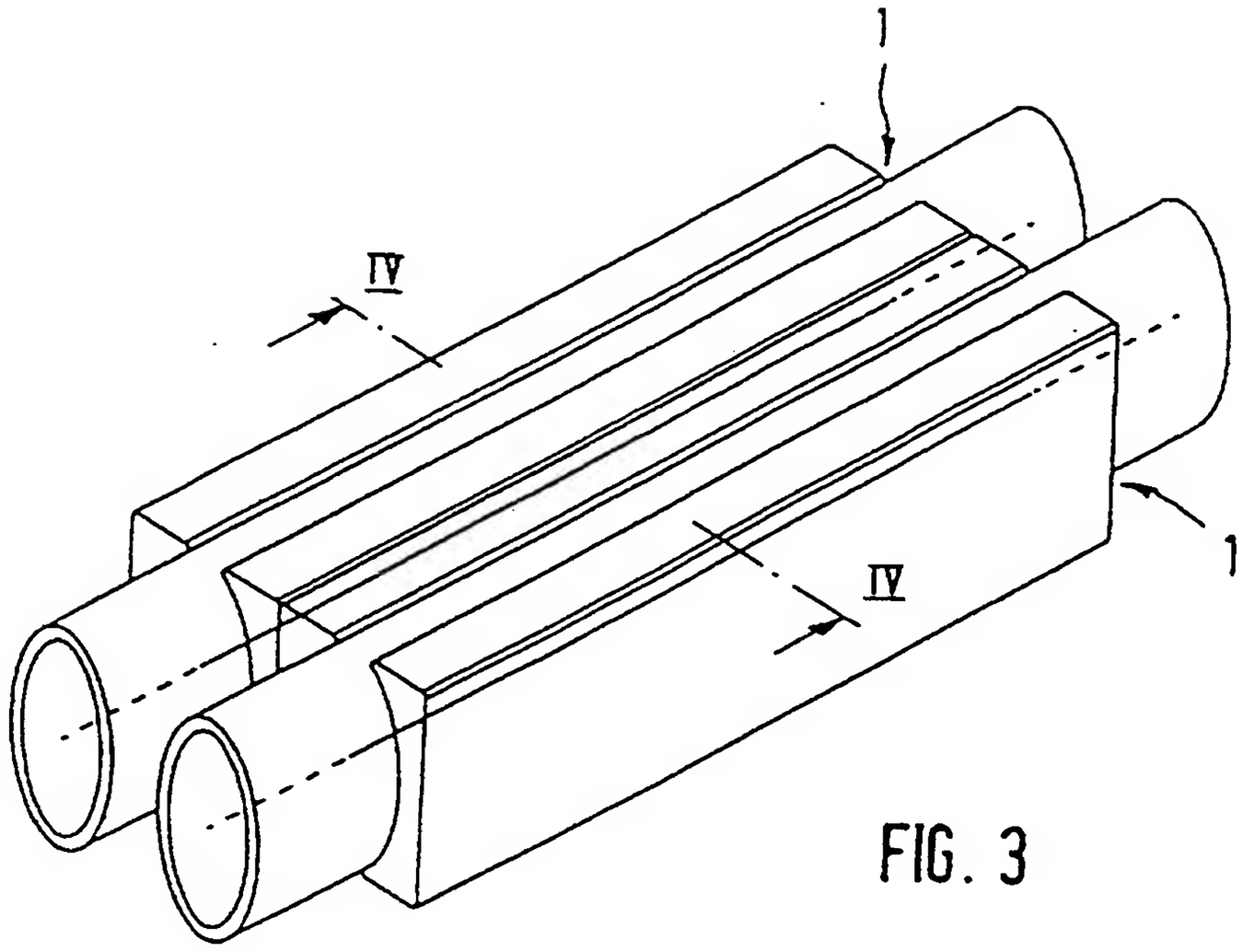

FIG. 3

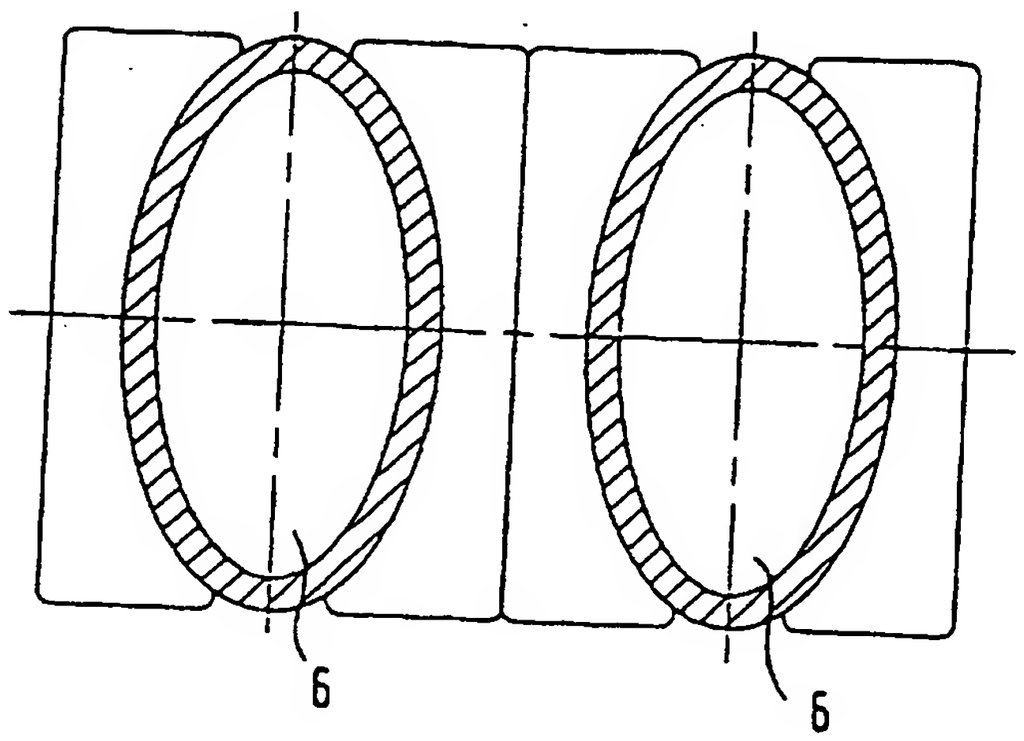

FIG. 4

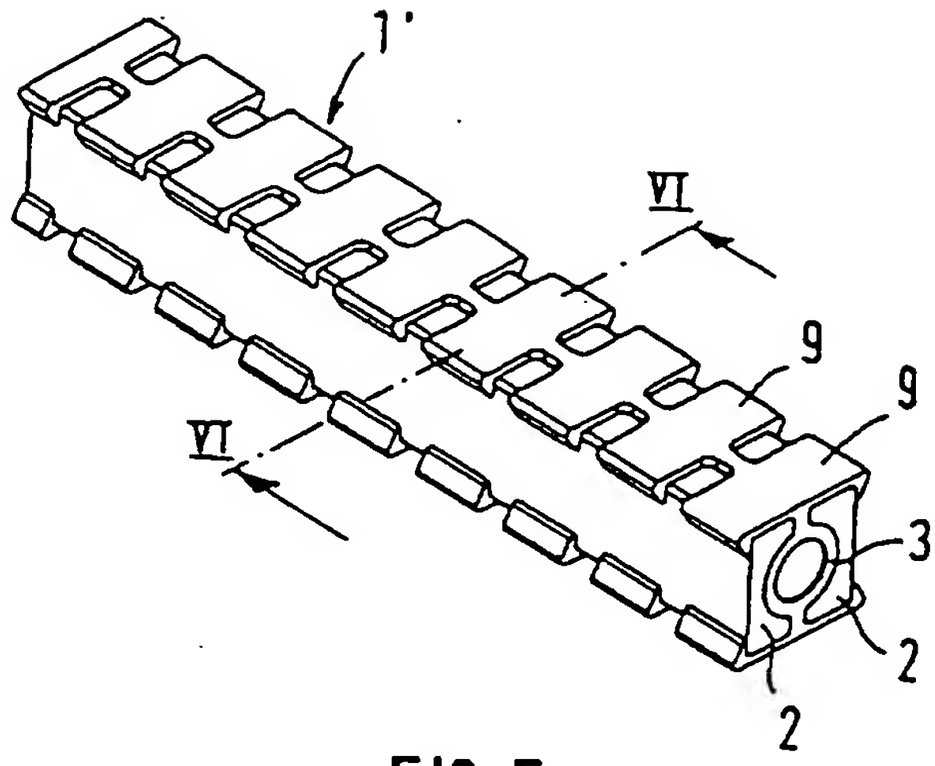

FIG. 5

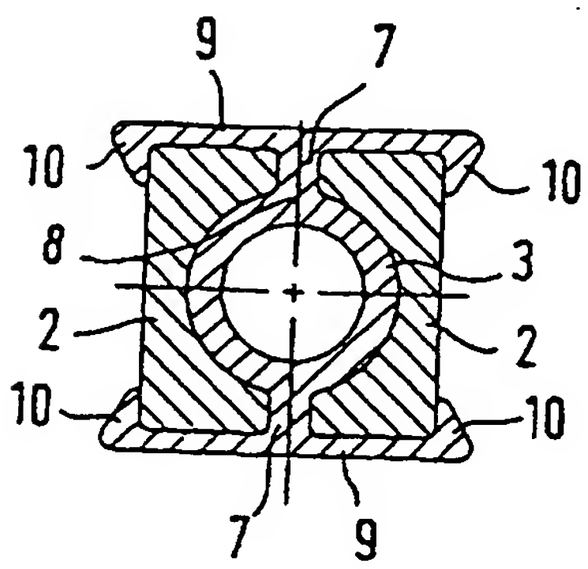

FIG. 6

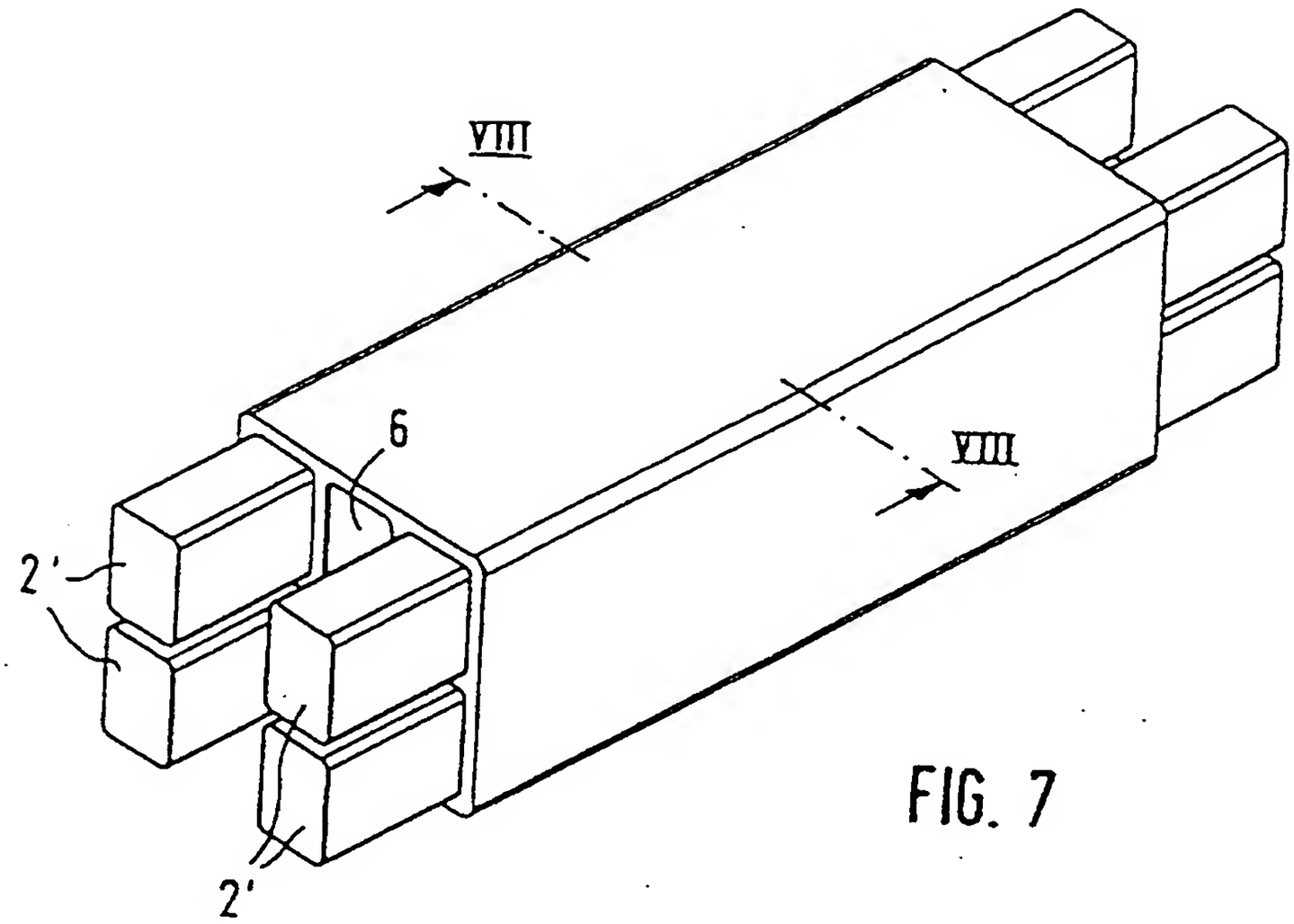

FIG. 7

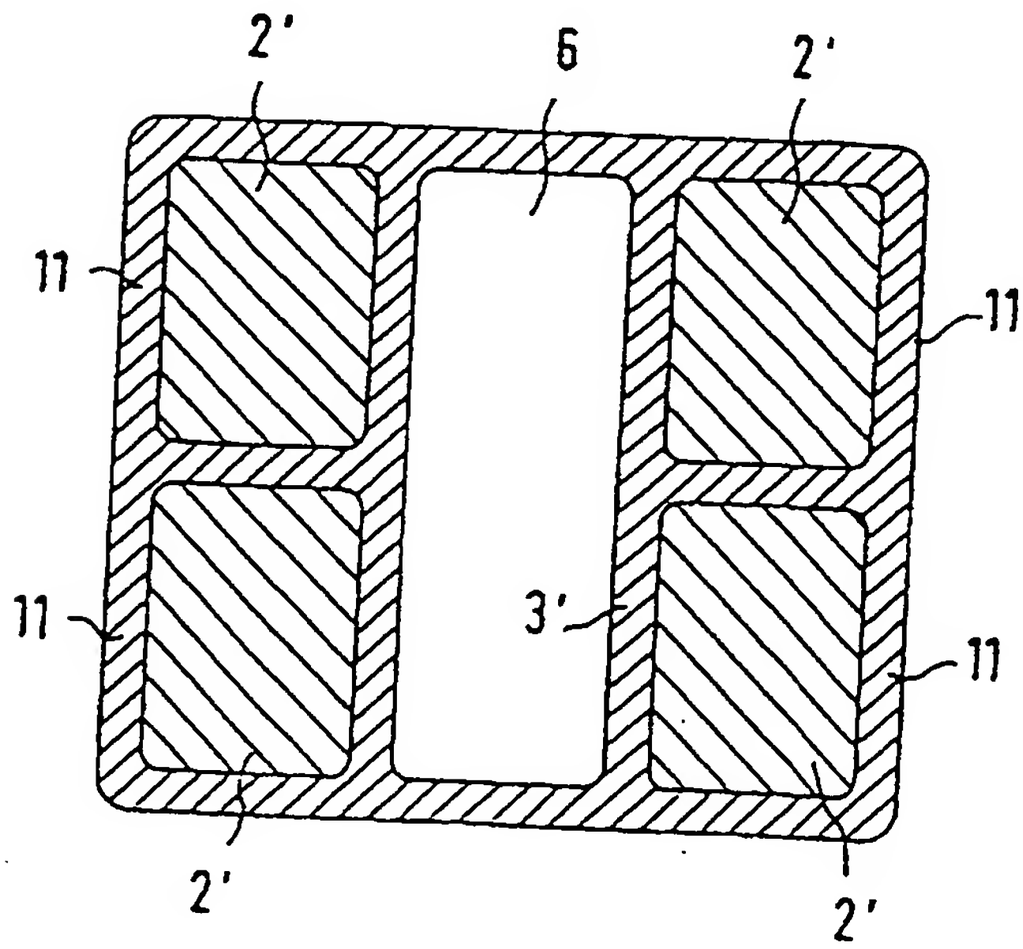

FIG. 8

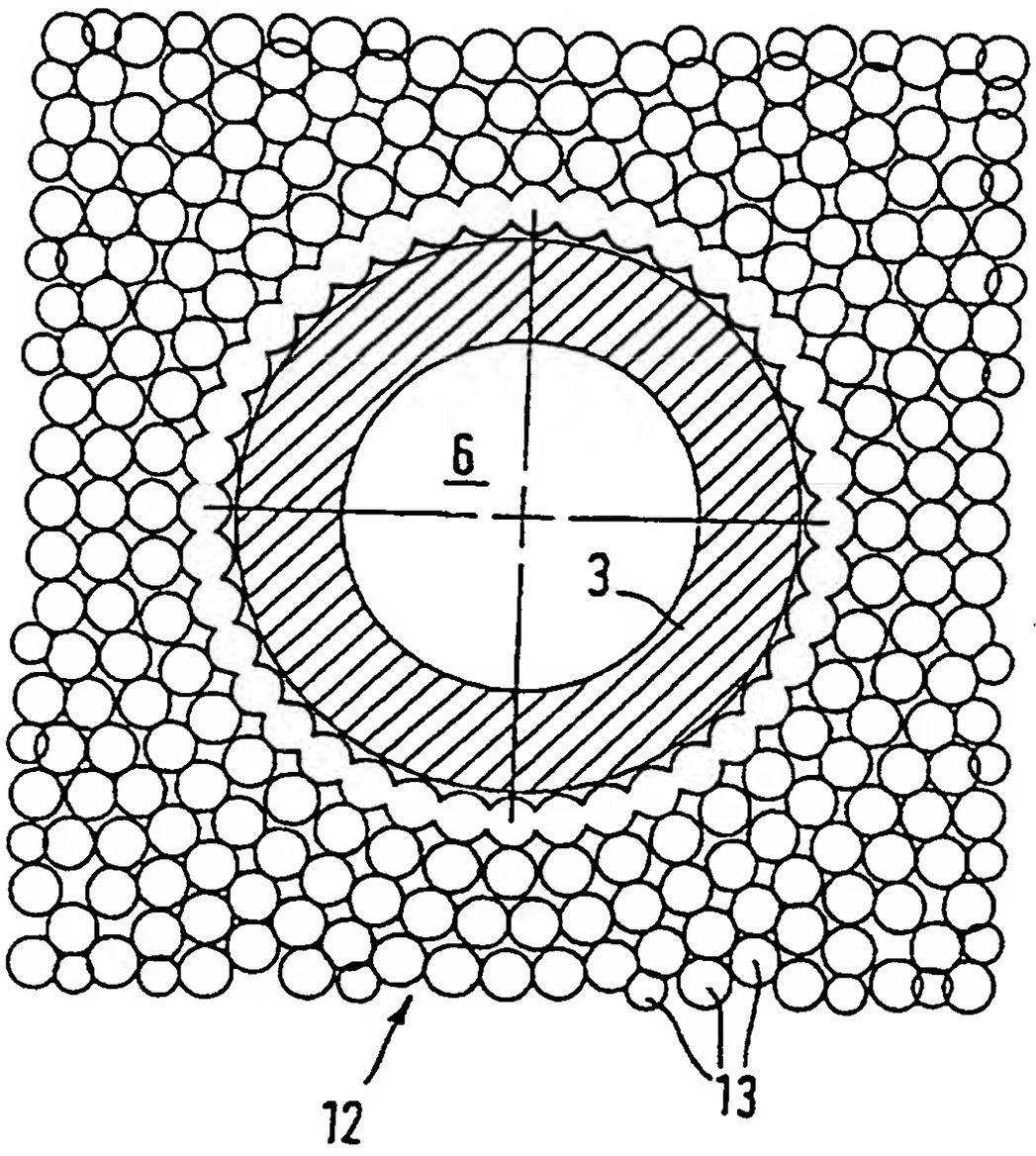

FIG. 9

DIRECT-COOLED MAGNET COIL

The invention relates to a direct-cooled magnet coil. The invention is particularly applicable to a gradient coil for magnetic resonance devices. The invention also relates to a method for the production of conductors for a direct-cooled magnet coil.

In order to guarantee the maximum permissible temperature of the gradient coil, it is necessary to dissipate the electrical power losses, which occur in the form of heat, in a controlled and effective manner. If it is thereby taken into consideration that the power losses that occur can be in the order of magnitude of more than 20 kW, the resultant demands on cooling are considerable.

A gradient coil, which consists of two individual coils electrically connected in series, is known from DE 34 45 448 A. The individual coils are arranged in opposing housing walls of a coil housing in such a way that a free area, as a cooling duct, remains between the individual coils.

EP 0 896 228 A describes an actively screened gradient coil system with primary and screening coils. The cooling pipes are located between these coils.

US 5,068,491 discloses a rigid conductor for a power supply with coolant channels.

A fluid-cooled induction coil is known from DE 25 44 275 A. Arranged inside an outer hollow conductor there is at least one further inner hollow conductor. Fluid flows through the interspace between the outer and inner hollow conductor.

The provision of a cooling duct in the electrical conductor for the windings of the gradient coil necessitates complete insulation of the coolant circuit on account of the high and in part different voltages in the region of the gradient coil. In situations where water is used as the coolant, the use of highly

distilled non-conductive water is necessary. However, the requirement for highly distilled non-conductive water both complicates and increases the cost of the operation to an enormous extent. In view of the high voltages and the direct contact between the water and the metal conductors, ionic contamination, and thus increased conductivity of the water, occurs even after a comparatively short time. This must be avoided without fail on account of the risk of high-voltage flashovers.

The invention seeks therefore to develop a direct-cooled magnet coil of the kind mentioned at the beginning in such a way that simple operation is possible with use of water that has not been conditioned. Moreover, a method for the production of conductors for a direct-cooled magnet coil is provided.

In accordance with the invention there is provided a direct-cooled magnet coil in which the conductors for the windings are provided with an inner cooling duct for conducting a cooling fluid, wherein the conductors are formed as profiled segmental conductors, the individual profiled segments of which enclose a cooling pipe made of material that is not or is only slightly conductive electrically.

As a result of the development in accordance with the invention the cooling fluid is completely insulated from the inner wall of the electrical conductor to be cooled so that it is also of no consequence at all whether, when water is used, this water has, to a greater or less extent, great electrical conductivity on account of natural impurities. On the other hand, on account of the small wall thickness of the electrically insulating cooling pipes, cooling of the conductors of the coil windings by the cooling fluid takes place that is only impeded to a small extent and is quasi direct so that there is very effective cooling

which counteracts the risk of excessive heating of the magnet coil.

As a result of the fact that a small amount of space is required for a design of a gradient coil in accordance with the invention in comparison with previous variants with direct cooling and high expensive external insulation or indirect cooling with cooling windings surrounding the gradient windings, the gradient-coil windings can be positioned in a more extreme position radially, this effecting an additional gain in field-generation effectiveness.

The omission of water-conditioning measures in order to lower the specific electrical conductivity and in order to minimize corrosion effects with the conductor material simplifies and reduces the cost of the operation of a direct-cooled magnet coil that is set up in accordance with the invention.

The conductors for a direct-cooled magnet coil in accordance with the invention can be set up in such a way that the conductor segments are intertwisted individual wire strands of a braided conductor covering the cooling pipe, in which case the production of such a conductor can preferably be effected in such a way that the individual wire strands are spun around the cooling pipe.

A design in which the profiled segments are rectangular rods with channels which are semicircular in cross section and enclose the cooling pipe in a form-locking manner has proved to be particularly advantageous in extensive tests that form the basis of the present invention. Such a structure can be manufactured very easily, in which case the conductors, which are rectangular in cross section, also correspond to the profiled shape which is standard for highly loaded gradient coils and which can easily be laid over formers. Further individual conductors, that is, both

solid conductors and braided conductors, can be applied to the outer surfaces of the profiled segments in this connection in order to increase the effective conductor surfaces.

According to a further variant of the development of the invention, holding webs, which embrace the conductor segments supporting them at least in part, can be preformed on the cooling pipe, for example in such a way that preformed on the cooling pipe there are longitudinal webs which are offset in respect of each other by 180° and preformed on which there are in turn transverse hook webs which are spaced apart and project on both sides. This latter embodiment produces a flexible plastics component so that it is possible to bend the finished conductor in a problem-free manner - the actual conductor segments, made, for example, of copper, can after all in any case be bent easily whilst retaining their shape.

In further development of the invention it can then be provided that lateral tubular profiled sections, each receiving a profiled segment in a form-locking manner, be preformed on the cooling pipe which is preferably rectangular in cross section. These lateral tubular profiled sections are then advantageously to be rectangular in cross section and form a smooth, rectangular outer contour. If applicable, in this connection slots spaced apart in parallel can be provided in the walls of the lateral tubular profiled sections that constitute the outer contour in order - in a manner similar to that in the case of the exemplary embodiment described above with the transverse hook webs which are spaced apart - to enable the finished conductors to be bent more easily whilst retaining their cross-sectional shape.

The production of a conductor with profiled segments of the electrical conductor arranged in

lateral tubular profiled sections of the cooling pipe can be effected in a very simple manner by means of coating or extrusion methods with use of thermoplastic plastics materials, as set out in claim 15.

For a better understanding of the present invention, and to show how it may be brought into effect, reference will now be made, by way of example, to the accompanying drawings, in which:

Figure 1 shows a simplified perspective view of a cooling pipe which is enclosed by two conductor segments;

Figure 2 shows an enlarged section along the line II-II in Figure 1;

Figure 3 shows a perspective view of a double conductor that is set up out of two conductors with an insulated cooling duct in accordance with Figure 1;

Figure 4 shows an enlarged section along the line IV-IV in Figure 3;

Figure 5 shows a modified embodiment of a segmental conductor in accordance with the invention with hook webs which embrace the conductor segments in a supporting manner;

Figure 6 shows a section along the line VI-VI in Figure 5;

Figure 7 shows a perspective view of a conductor in accordance with the invention with a rectangular cooling pipe and tubular profiled sections surrounding the latter for the purpose of receiving the profiled segments of the conductor in a form-locking manner;

Figure 8 shows a cross section along the line VIII-VIII in Figure 7; and

Figure 9 shows an arrangement of a conductor in

accordance with the invention in which a braided conductor has been spun around the cooling pipe.

In the case of the exemplary embodiment in accordance with Figures 1 and 2, the profiled segmental conductor 1 consists of two profiled segments 2 formed as rectangular rods with channels 4 which are semi-circular in cross section and which in a form-locking manner enclose a cooling pipe 3 made, for example, of plastics material. In the case of the exemplary embodiment shown in Figures 1 and 2, in which the two profiled segments can be moved in relation to each other so that close radii of curvature are possible, in addition to the two profiled segments 2 two further individual conductors 5 are also provided that are applied to the outer surfaces of the profiled segments 2 in order to increase the effective conductor surface. These additional individual conductors 5 could, in this connection, also be formed with a structured surface or, for example, be formed as braided conductors.

Figures 3 and 4 show a double conductor consisting of two conductors 1 which are arranged side by side and which are provided with an inner cooling pipe. In this way, given particularly thick highly loaded individual conductors for gradient coils, a structure can then result that is cooled in a simpler and more effective manner than if a correspondingly larger structure of the individual conductor arrangement in accordance with Figures 1 and 2 were chosen. The connection of a plurality of such individual conductors to form a component, as in Figures 2 and 3, if applicable even with the arrangement of such double conductors in accordance with Figures 2 and 3 one upon the other, is simpler in terms of manufacturing techniques and produces more effective cooling, since the paths from the development of the heat in the conductor to the

cooling fluid, generally water, are shorter in the cooling duct 6 of the cooling pipe.

The direct-cooled conductor in accordance with Figures 5 and 6 comprises a cooling pipe 3 with longitudinal webs 7, which are preformed thereon so as to be offset in relation to each other by 180° and preformed on which there are in turn transverse hook webs 9 which extend vertically in relation to the central plane 8 of the longitudinal webs and the hooks 10 of which embrace the profiled segments 2 and thereby support them. In the case of the arrangement in accordance with Figures 5 and 6 it is thus not necessary to connect the portions with each other in a special way, as in the case of the exemplary embodiment in accordance with Figures 1 to 4. As a result of the spacing of the transverse hook webs 9, a structure results that can be bent very easily so that the ease of bending whilst retaining the shape with close bending radii of the metallic profiled segments 2 is also further guaranteed for the whole direct-cooled conductor with the cooling pipe and the webs preformed thereon.

A modified embodiment of a direct-cooled conductor in accordance with the invention with an inner cooling duct 6 and a holding support pertaining to the profiled segments 2' is shown in Figures 7 and 8. In this connection, the substantially rectangular cooling pipe 3' is surrounded by four tubular profiled sections 11 which together with the cooling pipe 3' form a smooth rectangular, in the exemplary embodiment shown square, outer contour and are laterally connected, in which case this structure having the embedded profiled segments 2' can be obtained by means of an extrusion process.

Finally, Figure 9 shows a cross section through an embodiment of a conductor in accordance with the

invention in which the cooling body 3 is embedded in a litz conductor 12, preferably with the individual wire strands 13 of the braided conductor 12 spun around it. This embodiment, however, is less favourable with regard to the heat transfer from the outer wire strands to the cooling fluid running in the cooling duct 6 than the variants shown before. The advantage of this exemplary embodiment is low electrical resistance at high frequencies as a result of division into many individual currents through the conductor.

CLAIMS

1. Direct-cooled magnet coil in which the conductors for the windings are provided with an inner cooling duct for conducting a cooling fluid, wherein the conductors are formed as profiled segmental conductors, the individual profiled segments of which enclose a cooling pipe made of material that is not or is only slightly conductive electrically.

2. A direct-cooled magnet coil as claimed in claim 1 wherein the cooling pipe is made of a flexible plastics material.

3. Direct-cooled magnet coil according to claim 1 or 2, wherein the profiled segments are intertwisted individual wire strands of a braided conductor covering the cooling pipe.

4. Direct-cooled magnet coil according to claim 1 or 2, wherein the profiled segments are rectangular rods with channels which are semicircular in cross section and enclose the cooling pipe in a form-locking manner.

5. Direct-cooled magnet coil according to one of claims 1 to 4, wherein further individual conductors are applied to the outer surface of the profiled segments.

6. Direct-cooled magnet coil according to any preceding claim, wherein holding webs which embrace the profiled segments supporting them at least in part, are preformed on the cooling pipe.

7. Direct-cooled magnet coil according to claim 6, wherein longitudinal webs are preformed on the cooling pipe which longitudinal webs are offset in respect of each other by 180° and there are transverse hook webs preformed on the longitudinal webs, which transverse hook webs are spaced apart and project on both sides.

8. Direct-cooled magnet coil according to claim 5

or 6, wherein lateral tubular profiled sections each receiving a profiled segment in a form-locking manner, are preformed on the cooling pipe.

9. Direct-cooled magnet coil as claimed in claim 8 wherein the cooling pipe is rectangular in cross section.

10. Direct-cooled magnet coil according to claim 8 or 9, wherein the lateral tubular profiled sections are rectangular in cross section and form a smooth, rectangular outer contour.

11. Direct-cooled magnet coil as claimed in claim 10, in which the outer contour is square.

12. A direct-cooled magnet coil substantially as herein described, with reference to the accompanying drawings.

13. A gradient coil for magnetic resonance devices comprising the direct-cooled magnet coil as claimed in any preceding claim.

14. A magnetic resonance device having a gradient coil as claimed in claim 13.

15. Method for producing a conductor for a direct-cooled magnet coil in accordance with one of claims 8-11, wherein the cooling pipe with tubular profiled sections preformed thereon is made by means of extrusion-pressing with simultaneous embedment of the profiled segments.

The Patent Office

INVESTOR IN PEOPLE

Application No:	GB 9920411.7	**Examiner:**	Kalim Yasseen
Claims searched:	1-15	**Date of search:**	21 February 2000

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): F4U (UA,U23, U29); H1P (PHC, PSK); H1T (T1F)

Int Cl (Ed.7): G01R (33/38, 33/385); H01F (5/00, 27/08, 27/10, 27/12, 27/16)

Other: Online: EPODOC, JAPIO, WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	US 5 438 182 A	(GOLD) a choke coil apparatus	
A	US 4 593 261 A	(SIEMENS) a device for cooling a magnet system	
A	US 4 577 175 A	((MARELCO) a transformer with fluid cooled windings	
X	Online (JAPIO) abstract for JP550070015 A, coils having a cooling duct 14 there between		at least 1-2

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

The Patent Office

12

Application No: GB 9704999.3
Claims searched: 1 to 13

Examiner: J L Freeman
Date of search: 19 May 1997

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H1A (AKC, AKV)

Int Cl (Ed.6): G01R 33/385; H01B (7/34)

Other: On-line: EDOC, WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	GB 2040546 A	(A B Volvo) All figures	1
A	GB 1105906	(Soc Anon Des Usines Chausson) All figures	1

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.